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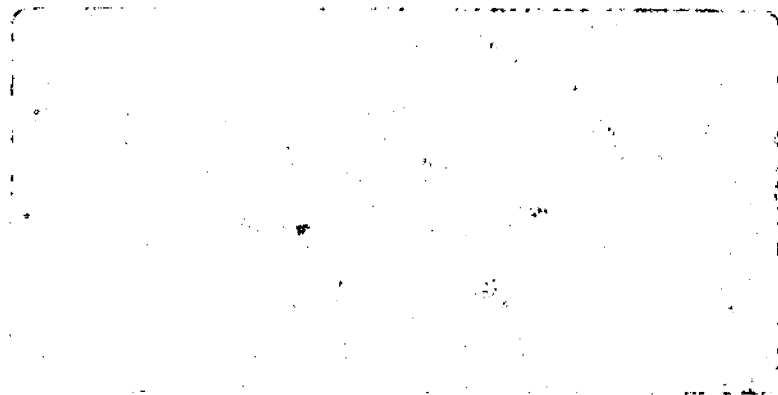
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IBM PROGRAM GUTS -  
DETAILED DESCRIPTION AND FLOW  
Fred Safier and Carol Hansen  
September 9, 1960

IBM PROGRAM GUTS—  
DETAILED DESCRIPTIONS AND FLOW

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IBM PROGRAM GUTS -  
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Fred Safier and Carol Hansen

Lawrence Radiation Laboratory  
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ABSTRACT

An IBM program GUTS for kinematic analysis of bubble chamber interactions is described and flow is diagrammed. A list of possible rejects while running GUTS, with their causes, is included.

## IBM PROGRAM GUTS—DETAILED DESCRIPTION AND FLOW

Fred Safier and Carol Hansen

Lawrence Radiation Laboratory  
University of California  
Berkeley, California

September 9, 1960

### INTRODUCTION

GUTS is an IBM program of approximately 6000 words, written in the form of a closed subroutine. It is designed to adjust variables pertaining to tracks at an interaction vertex in a cloud or bubble chamber by the method of least squares, subject to constraints. It calculates a  $\chi^2$  for the adjusted variables and calculates errors stated on the best-fitted variables. The equations of GUTS are completely described by J. P. Berge, F. Solmitz, and H. D. Taft.<sup>1</sup> For further amplification of the method and discussion of its extension see the following Alvarez Group memos:

1. Physics Memo 86 by Jon Peter Berge;
2. Physics Memo 187 by Frank T. Solmitz;
3. Physics Memo 190 by Frank T. Solmitz;
4. Physics Memo 188 by Orin Dahl.

The first one is an amplification of UCRL-9097,<sup>1</sup> including descriptions of additional constraint classes, etc., to bring the report up to date. The next two memos describe the possible directions in which GUTS should be modified in future versions; the first is an extension of least-squares-with-constraints method, and the second describes the convergence testing. The last memo describes additional constraint classes which could profitably be put into future versions of GUTS.

This paper is divided into four sections; first, a glossary of all terms used in the flow diagrams; second, the detailed flow diagrams of GUTS as it exists in version 4.3; third, a list of all rejects possible when running GUTS and finally the over-all flow diagram of GUTS, which is valid for all versions.

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<sup>1</sup>J. Peter Berge, Frank T. Solmitz, and Horace D. Taft, Digital-Computer Analysis of Data from Bubble Chamber III. The Kinematical Analysis of Interaction Vertices, UCRL-9097, March 15, 1960.

In reference to the detailed flow diagrams, the following should suffice to clarify the sequence:

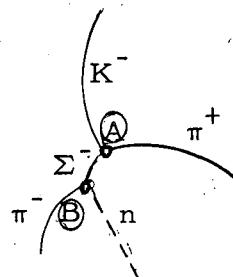
GUTS is logically divided into six sections: the input initialization and checking, (pp. 1 and 2); the kinematics involved in calculating constraints and constraint derivatives, (pp. 3 through 4); the separate equations for the various constraint classes, (pp. 5 through 16 and 32 through 36); the constraint modifications and testing, (pp. 16 through 18); the stepping, (pp. 19 through 20); and finally, the error propagation and matrix unpacking, (pp. 21 through 24). In addition to the above, GUTS contains certain utility routines, which do swimming of curvatures, algebraic signing, and other small tasks. These are in the form of closed subroutines of the program, and are diagrammed here for the sake of completeness, even though some of them are not referred to in the body of the flow diagram (pp 25, 26, 29, 30, and 31). Finally, there is the cutstep procedure, (p. 27 and 28), an explanation of which is given in UCRL-9097<sup>1</sup>.

GUTS was coded in such a way that it would be as easy as possible to insert new constraint classes. In particular, there is logic in GUTS to enable one to program and insert the imposition of a wall on the zero-C case, to do a 2C fit with only two particles, and to do a four-constraint, two-vertex fit. These routines themselves are not in the version of GUTS described in this paper, however, the last of these has been programmed and inserted into later versions of GUTS, and the flow diagram is included here (as pages 32-36). This constraint class occurs, for example, in the fitting of the reaction  $K^- + p \rightarrow \Sigma^- + \pi^+$ ,  $\Sigma^- \rightarrow \pi^- + n$ .

The sigma connects vertices A and B, and has unmeasurable momentum.

The neutron is completely unseen. This is a 3C vertex followed by a 1C vertex, fitted simultaneously. If this entrance is tried in

GUTS 4.3 it leads to a reject. Also, at present, the attempt to impose a wall on zero C leads to a reject.



All diamonds containing RJCTn lead out of GUTS to the body of KICK, where it is understood that GUTS has run into trouble and for one reason or another rejected the hypothesis. The meaning of each reject should be clear from the flow diagrams, but for an amplification or sometimes merely a repetition, see Pages 38 and 39.



All notations in these flow diagrams are defined in Alvarez Memo 86 or in the glossary of this paper. The only exception is that on pages 1 and 23, I, M, P, and L refer to KLOCI, KLOCM, KLOCP, and KLOCL respectively, as defined in the GUTS glossary.

## II. GLOSSARY OF TERMS USED IN GUTS

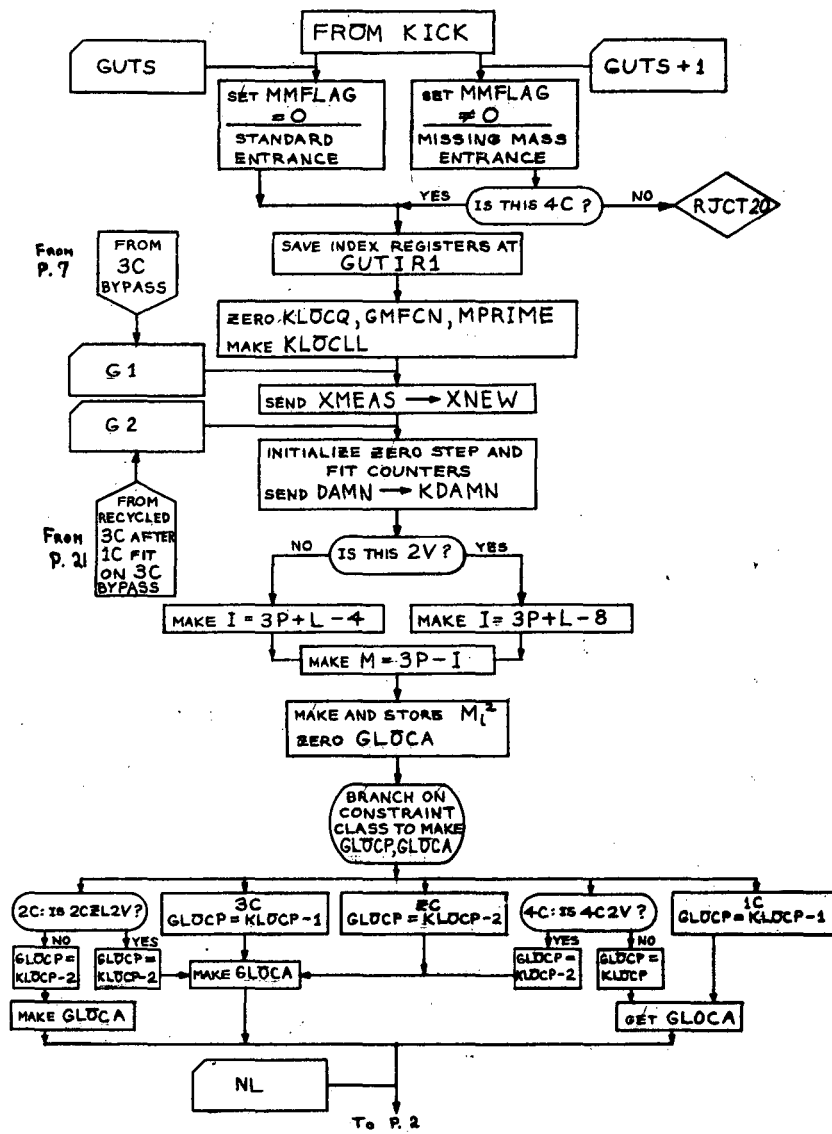
This glossary is intended to contain all locations frequently used by the program, whether or not they are referred to in Memo 86, or the GUTS flow diagrams. The numbers to the left of some of the definitions are not related to GUTS, and refer to the order in which these locations are to be found in SNYDER, storage shared by ZVERT and GUTS.

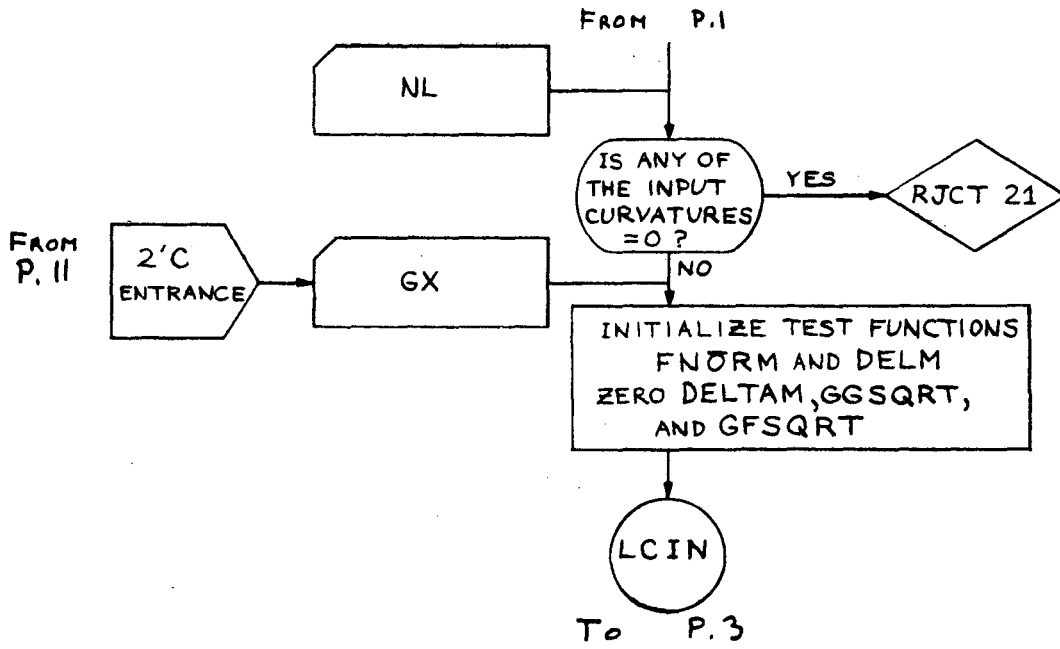
ADR	Block containing some addresses used by program.
ALFA	Range-Momentum exponent, set 0.283. See page V-9, Memo 86.
40→43. ALPHA	4-word block containing $\alpha_\lambda$ , the Lagrange multipliers. See page III-1 ff of Memo 86.
36→39. ALPHA1	4-word block containing the values of $\alpha_\lambda$ after the first step.
BLFCN	4-word block containing $b_\lambda$ . See page III-2 ff. of Memo 86.
CHECK	Acceptance level for the fractional difference between $\chi_A^2$ and $\chi_B^2$ . See page III-5 of Memo 86.
CONS	Block containing fixed-point constants of the program.
CORREL	90-word block containing $\delta\chi_\alpha^* \delta y_\beta^*$ matrix after a fit. See page III-7 of Memo 86.
DAMN	Sign of Zero C discriminant, set outside GUTS. See page V-10 of Memo 86.
49. DELM	Test function $\overline{\delta M^V}$ . See section III-b of Memo 86.
DELMOK	Level for $\overline{\delta M^V}$ acceptance.
48. DELTAM	After a step, contains $(\overline{\delta M^{V-1}})$ . After a cutstep type 5, contains the $\sqrt{F^{V2}}$ that was unacceptable. After a cutstep type 6, contains the $(\overline{\delta M^V})$ that was unacceptable. After a RJCT6, contains the quantity $\left  \frac{\chi_A^2 - \chi_B^2}{\chi_A^2} \right $ that was unacceptable.
DKUDXI	21-word block containing Zero C $K_u$ derivatives. See page V-17 ff of Memo 86.
DMMASS	Error on missing mass in missing-mass case. See page V-13 of Memo 86.
52. DUNPEE	Error on missing momentum in missing-mass case. See page V-13 of Memo 86.

EIL	84-word block containing $E_{i\lambda}^v$ . See page III-2 of Memo 86.
ELI	84-word block containing $(E^v)_{\lambda i}^T$ matrix.
ERROR	36-word block containing $\delta y_{\alpha}^* \delta y_{\beta}^*$ matrix after a fit. See page III-7 of Memo 86.
FCONS	Block containing floating-point constants of the program.
FIL	84-word block containing $F_{i\lambda}^v$ . See page III-1 of Memo 86.
FILOLD	Storage for $F_{i\lambda}^v$ while $F_{i\lambda}^{v+1}$ is being made.
FITCT	Fit counter. Is zero until first fit is obtained.
46. FNORM	Normalized constraint functions, $\sqrt{F^{v2}}$
FOK	Level for constraint-function acceptance.
6. GCONTR	Step counter.
7→13. GCONTR+1→8	CUTSTEP counters (equivalent to GCUTI →GCUT6.)
GDELX	21-word block containing $(\chi_i^{v+1} - \chi_i^v)$ after each step.
28→31. GFFCN	4-word block containing constraint functions ( $f_{\lambda}$ ). See page III-1 of Memo 86.
24→27. GFFCN1	4-word block containing the values of $F_{\lambda}$ after the first step.
45. GFSQRT	Contains the value of $\sqrt{(F^{v-1})^2}$ .
GINA	63-word block containing input error matrix $G_{ij}^{-1}$ . See page III-6 of Memo 86.
GINA1	63-word block containing central 3x3's of output error matrix $G_{ij}^{*-1}$ . See page III-6 of Memo 86.
GINOUT	441-word block containing full 3Px3P output error matrix. See section IV-b of Memo 86.
GLOCA	7-word block containing dimensions of output error matrix.
GLOCP	Number of completely measured particles.
GMFCN	$\chi_A^2$ . See pages III-1 ff., III-4, of Memo 86.
GMFCN+1	Zero-C pass counter (equivalent to ZCCTR).
GMFCN+2	Counter of number of cutsteps since last good step (equivalent to LQT).
GUTIR1	3-word block used to store index registers on entrance to GUTS.

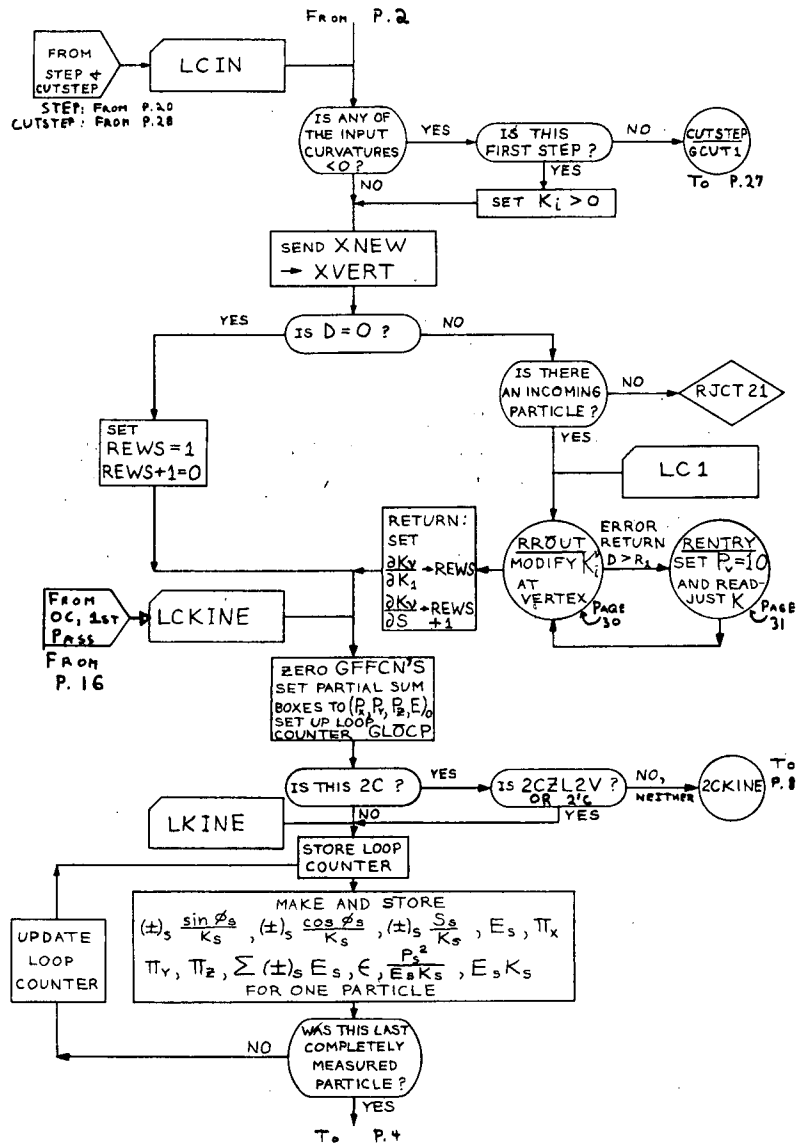
GYFCN	21-word block containing normalized step functions after a fit. See page III-7 of Memo 86.
HELI	126-word block containing $(HE^T)_{\lambda i}^{\nu}$ . See page III-3 of Memo 86.
HLM	16-word block containing $H_{\lambda\mu}^{\nu}$ . See page III-3 of Memo 86.
HLM1	16-word block containing $H_{\lambda\mu}^{-1}$ for this step.
HLM2	16-word block containing $H_{\lambda\mu}^{-1}$ for last step.
50. KDAMN	Sign of Zero-C discriminant inside GUTS. See page V-10 of Memo 86.
KINECT	Block of counters used in loops throughout program.
44. KLOCD	Distance specified from a vertex for the incident particle's curvature. See section IV-d of Memo 86.
3. KLOCI	Number of measured variables.
2. KLOCL	Number of constraints.
4. KLOCLL	Flag for anomalous constraint classes (1'C, 2'C, 2CZL2V, 3C bypass, 4C2V).
KLOCM	Number of missing variables.
1. KLOCP	Number of particles.
KLOCPP	Number of particles at vertex A in two vertex classes.
5. KLOCQ	Flag for 3C bypass (zero if not 3C bypass).
22. KLOCT	Target mass.
23. KLOCTT	Target mass at second vertex in a 2V constraint class.
15→21. KMASS	7-word block containing masses of particles.
KMSQ	7-word block containing squares of masses.
KNSTEP	Test level for too many steps.
KNSTEP+1	Test level for too many cutsteps.
LCAFCN	7-word block containing $E_s K_s$ during calculation of $F_{i\lambda}, F_{\lambda}, Y_a, V_{aj}$ .
LCBFCN	7-word block containing $\frac{p_s^2}{E_s K_s}$ during calculation of $F_{i\lambda}, F_{\lambda}, Y_a, V_{aj}$ .
LCDMTX	90-word block containing $V_{aJ}$ .
LCKCOS	7-word block containing x - momenta of each track.
LCKEGY	7-word block containing energies of each particle.
LCKSIN	7-word block containing y-momenta of each track.

- LCKTAN 7-word block containing z-momenta of each track.
- LMAX z-axis range of "0-length" particle in 2' C case = 6 x WALL.  
See page V-8 ff of Memo 86.
- MMASS Missing mass in missing-mass case. See page V-12 of Memo 86.
- MMAX Test level for  $\chi^2$  size at end of first step.
- MMFLAG Flag for missing-mass case. Zero if standard entrance.  
See page V-10 of Memo 86.
47. MPRIME  $\chi_B^2$ . See page III-4 of Memo 86.
35. PSEGY Partial sum of energies  $E$ . See page V-1 of Memo 86.
32. PSPX Partial sum of x-momenta  $\pi_x$ . See page V-1 of Memo 86.
33. PSPY Partial sum of y-momenta  $\pi_y$ . See page V-1 of Memo 86.
34. PSPZ Partial sum of z-momenta  $\pi_z$ . See page V-1 of Memo 86.
- PX 4-word block containing original momentum-energy-translation four-vector.
- REWS Block containing transformation derivatives from range-momentum routine. See section IV-d of Memo 86.
- RIPS+5 This location contains a  $10^{10}$ .
14. RJCT If a reject 13 has occurred in GUTS, this contains the location at which it occurred.
51. UNPEE Missing momentum in missing-mass case. See page V-12 of Memo 86.
- WALL X-Y Plane range of "zero-length" particle in 2' C case.  
See page V-8 ff of Memo 86.
- XMEAS 21-word block containing measured input variables. See page III-1 of Memo 86.
- XNEW 21-word block containing variables used for step.
- XOLD Storage for  $\chi_i^v$  while  $\chi_i^{v+1}$  is being made.
- XVERT 21-word block containing variables specified at vertex for each step.
- ZCCTR Zero-C pass counter.
- ZCKU 2-word block containing  $K_u$  in zero C case. See page V-14 of Memo 86.
- ZDISC Unsigned discriminant in ZC  $k_u$  calculation. See page V-17 of Memo 86.
- 2VFLAG Flag for two-vertex classes, set outside GUTS

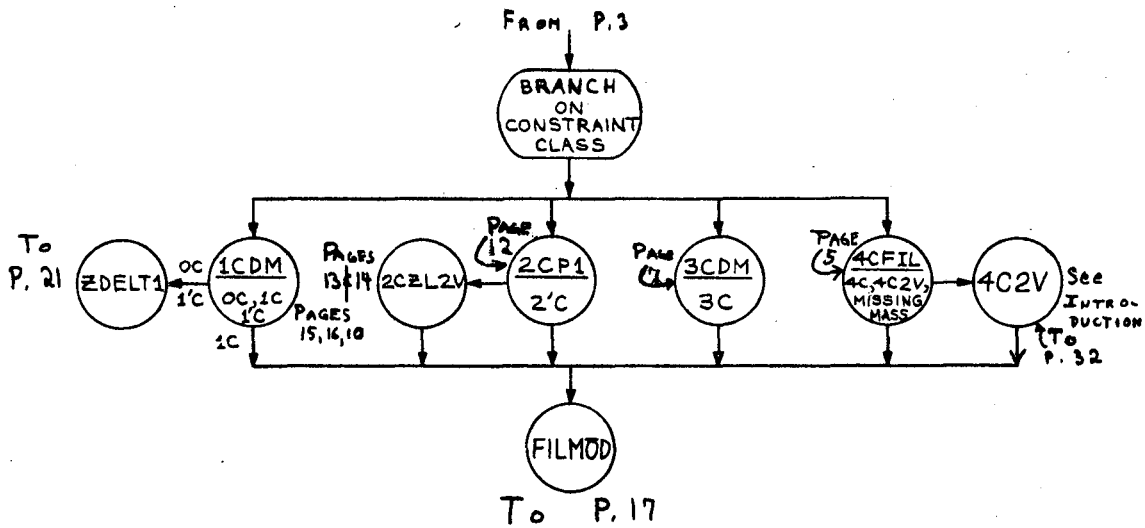




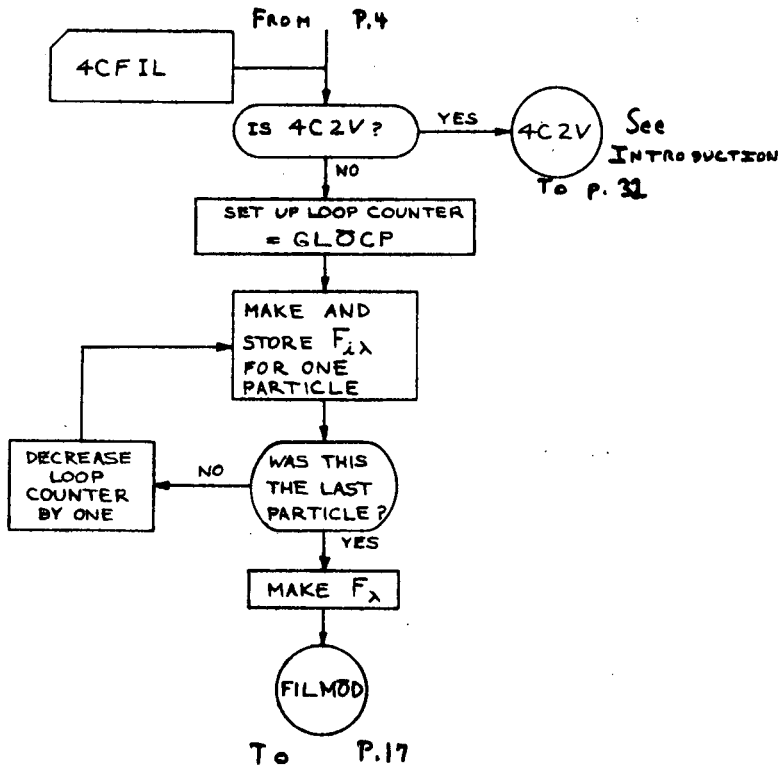
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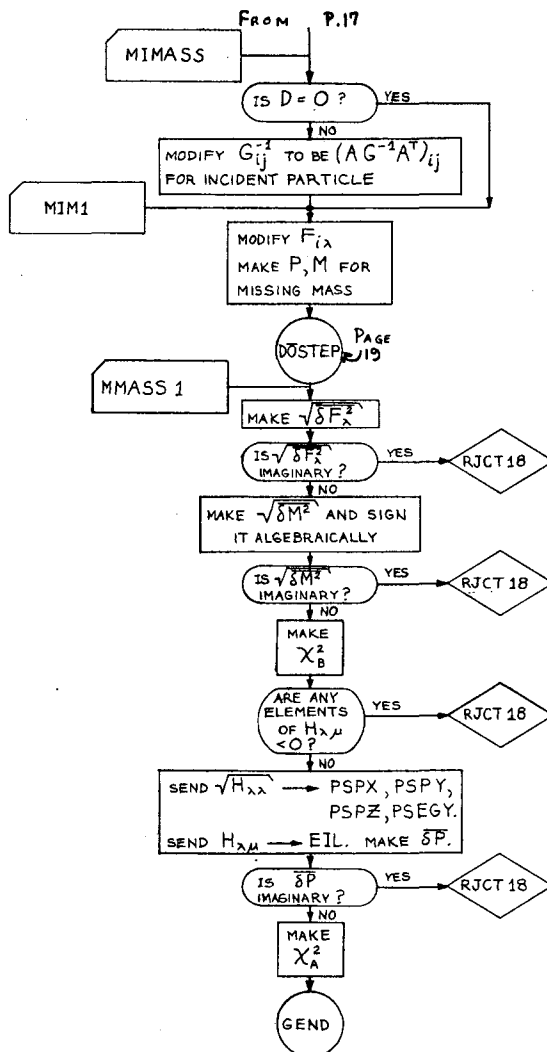




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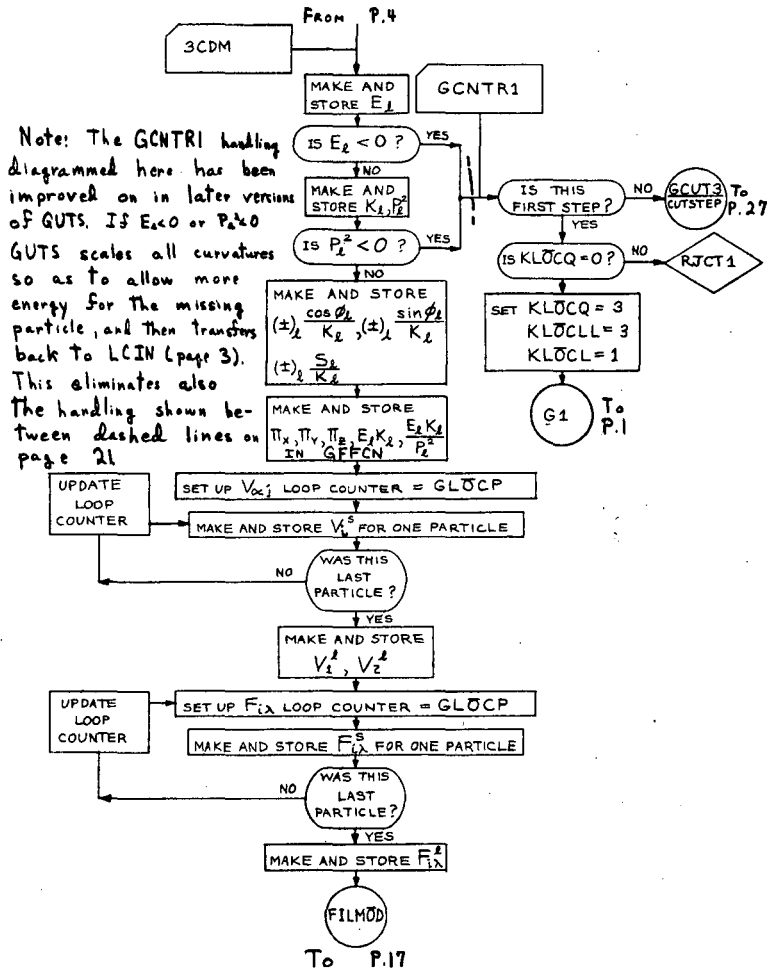


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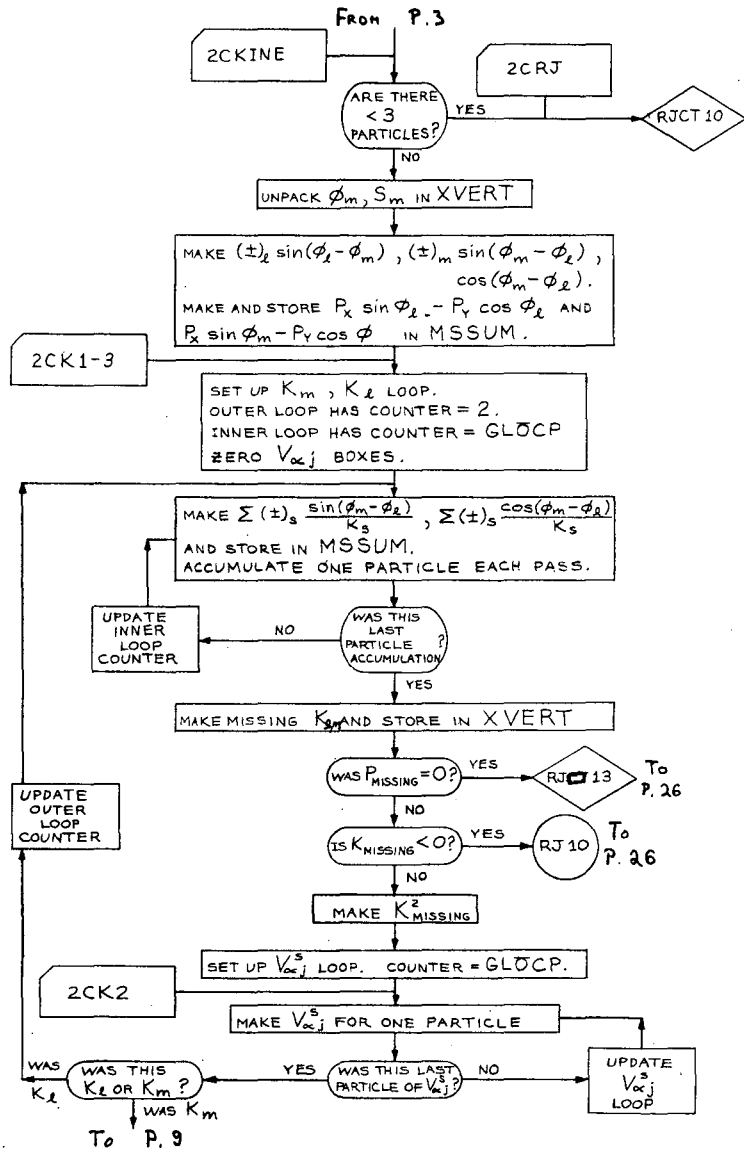


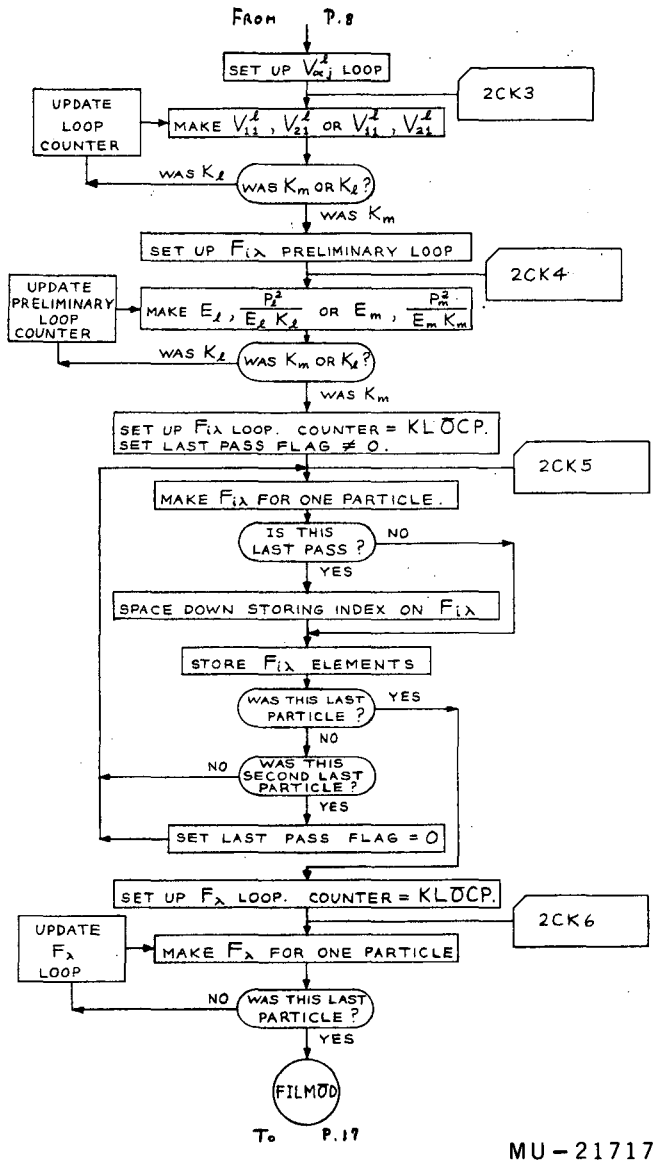
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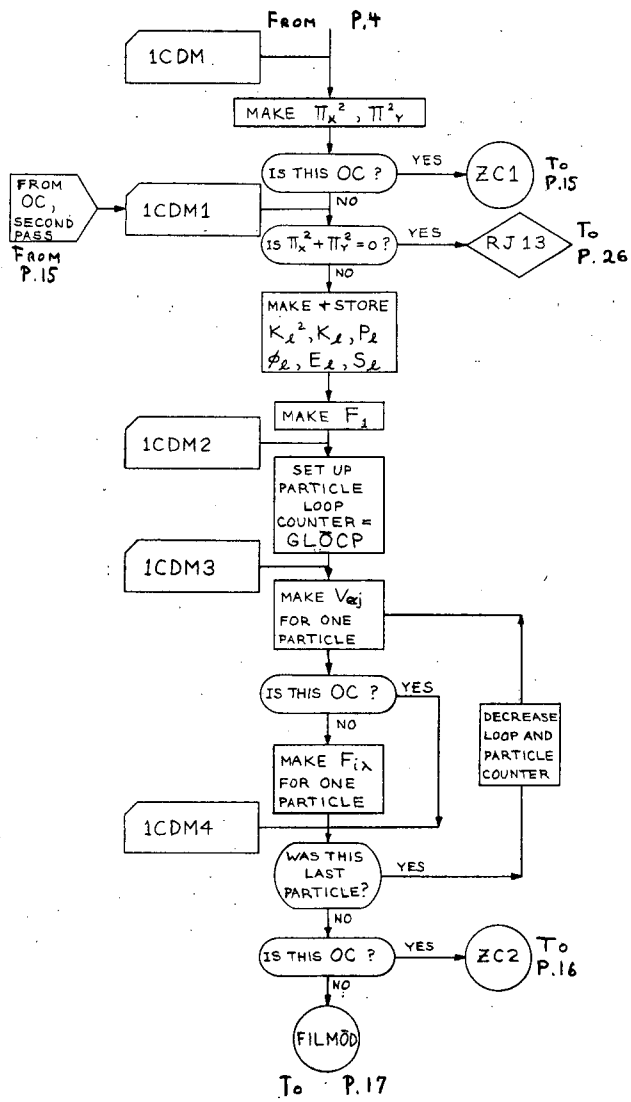
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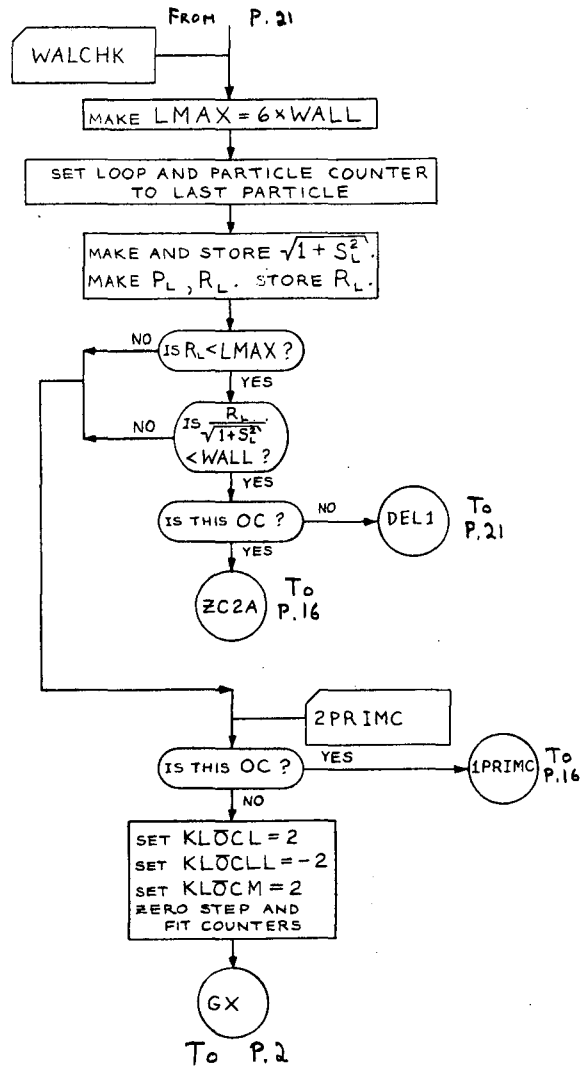
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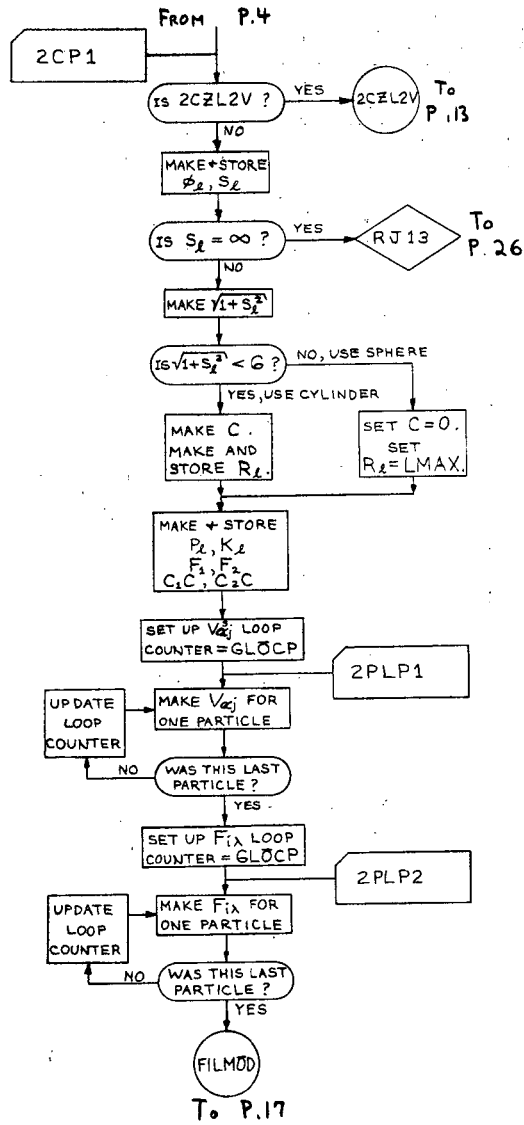




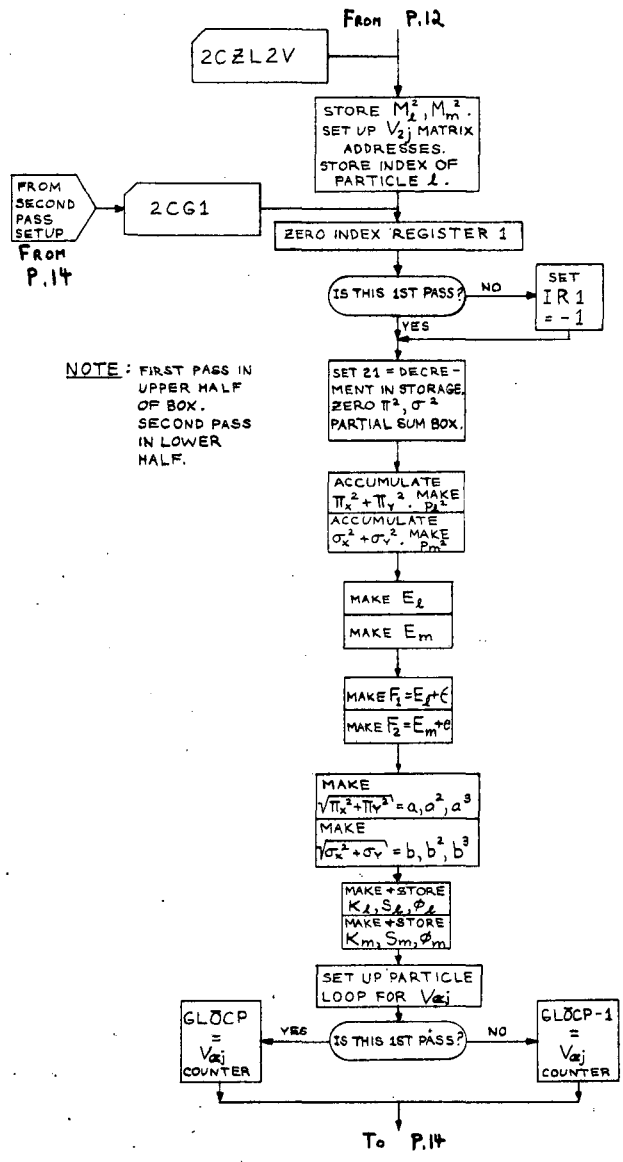
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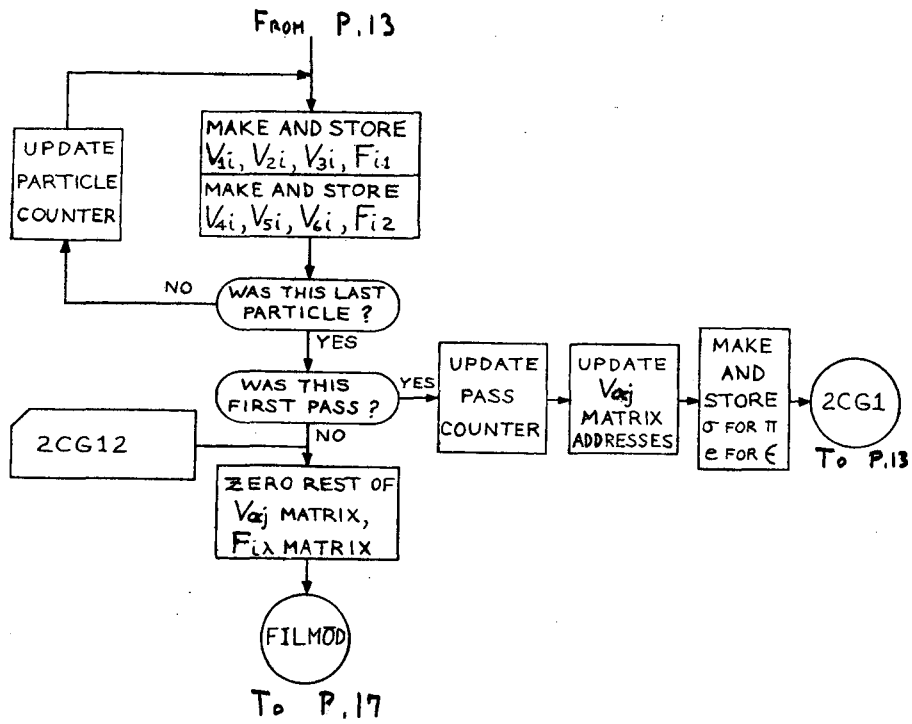




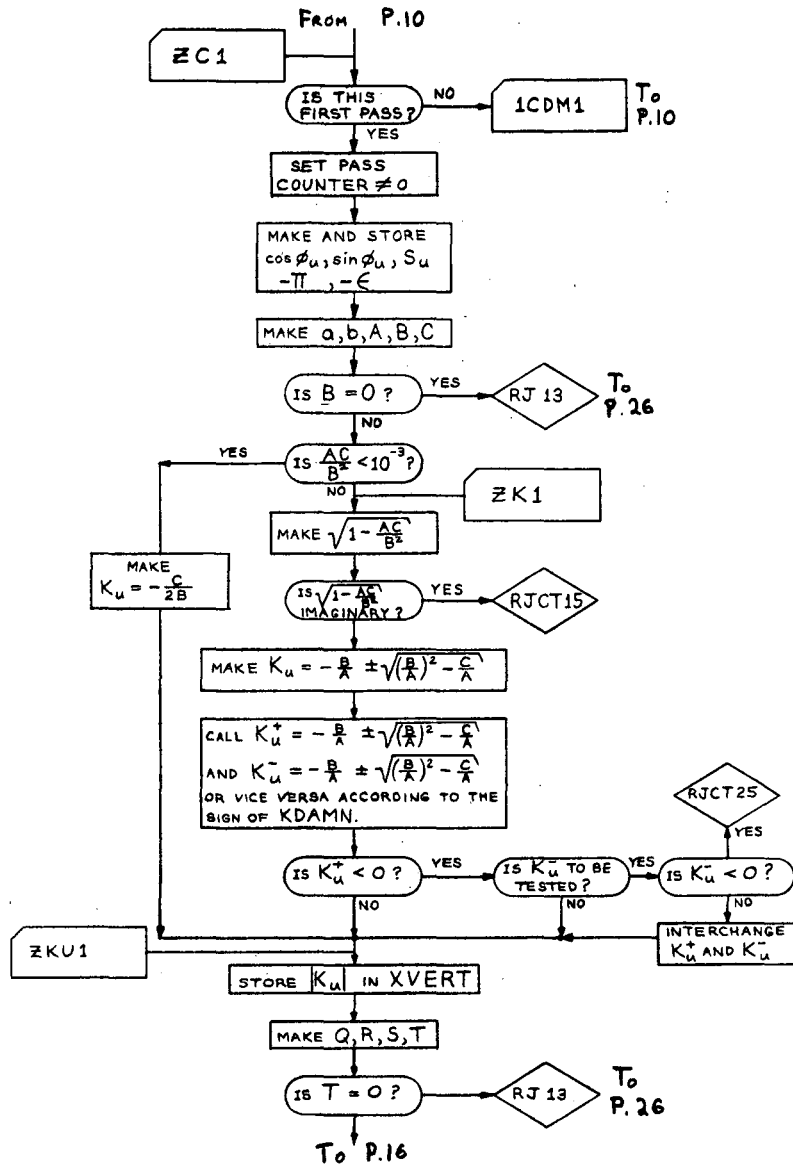
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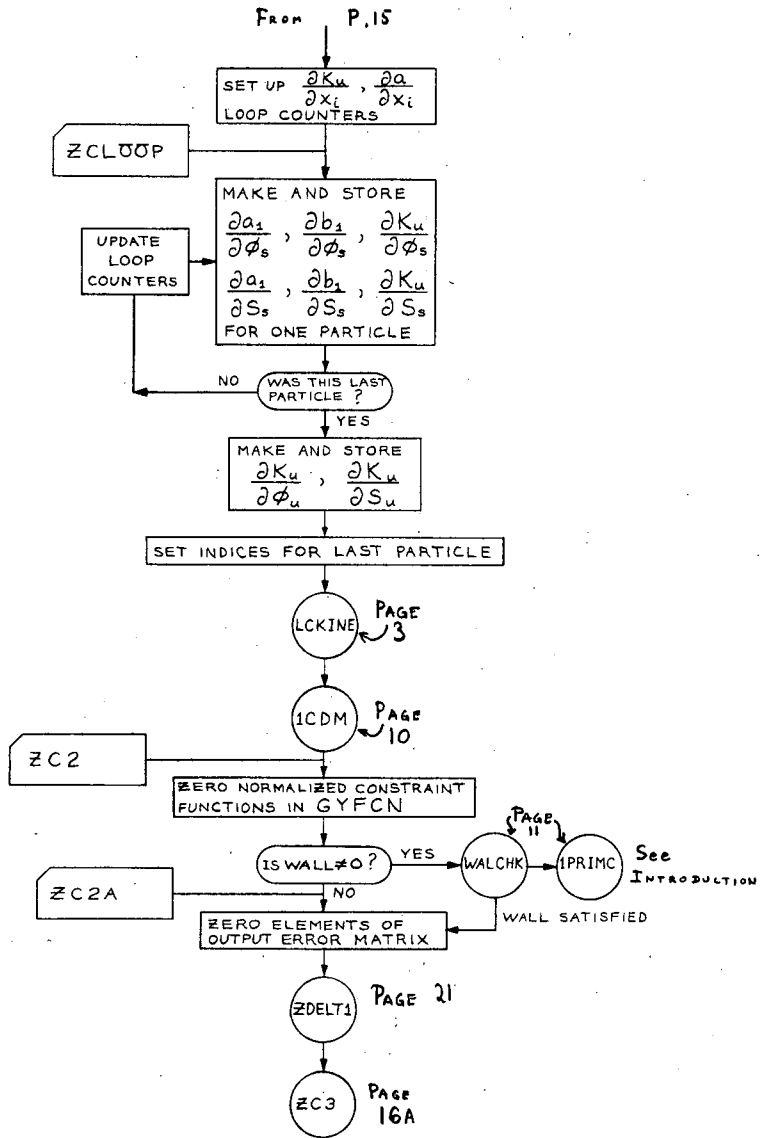


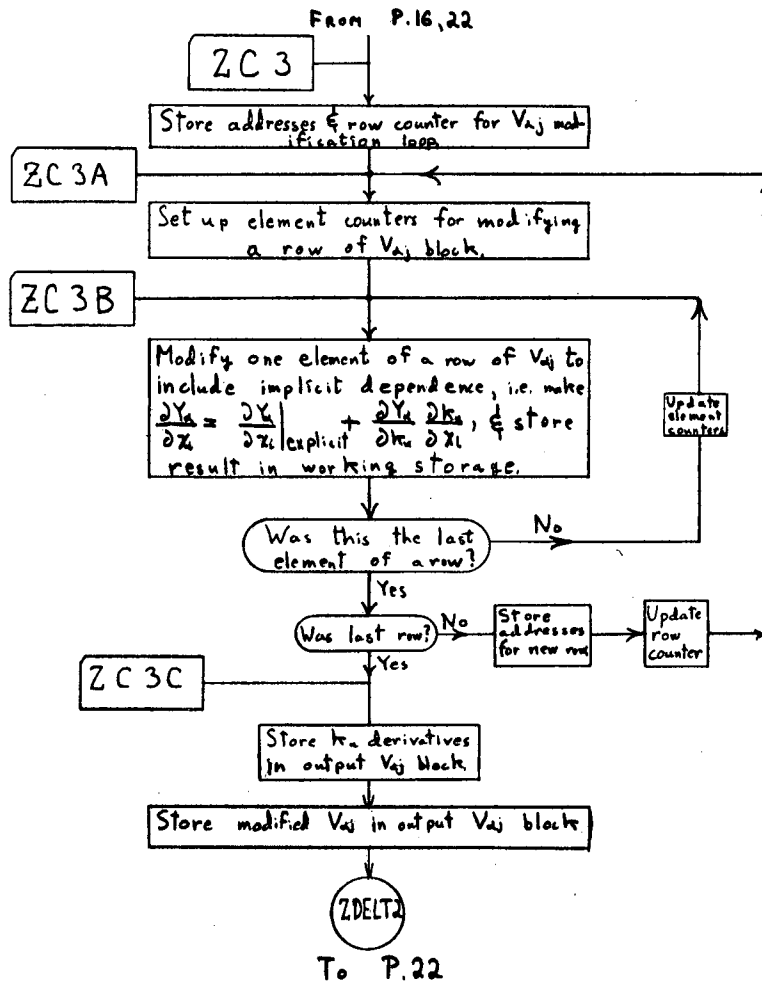
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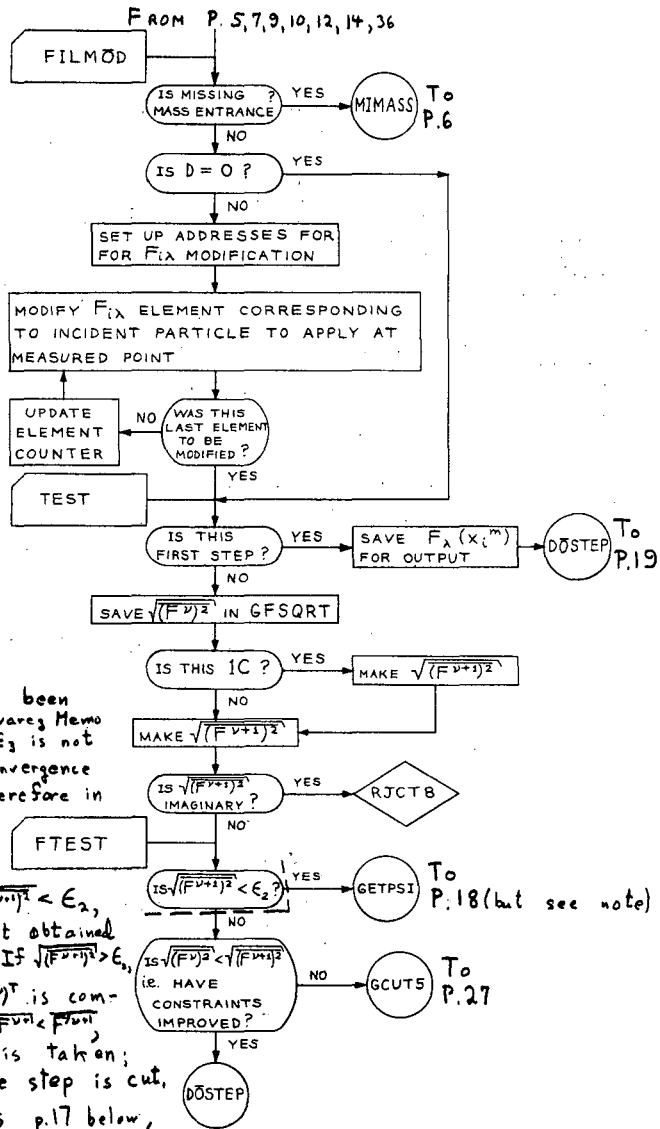


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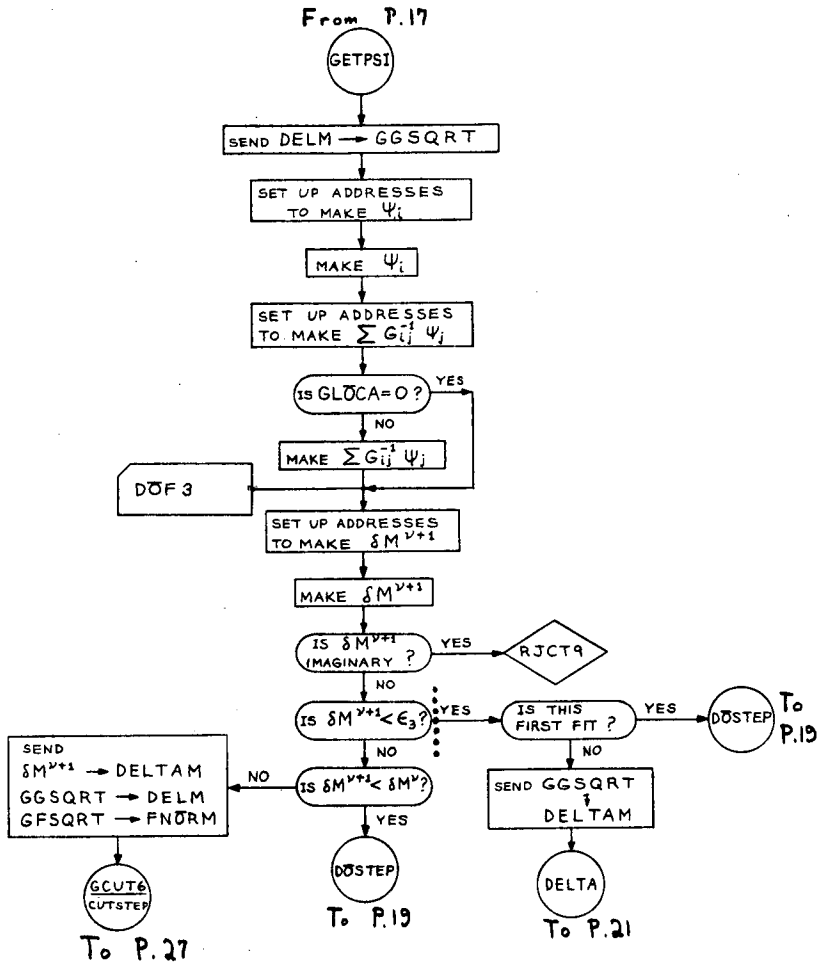




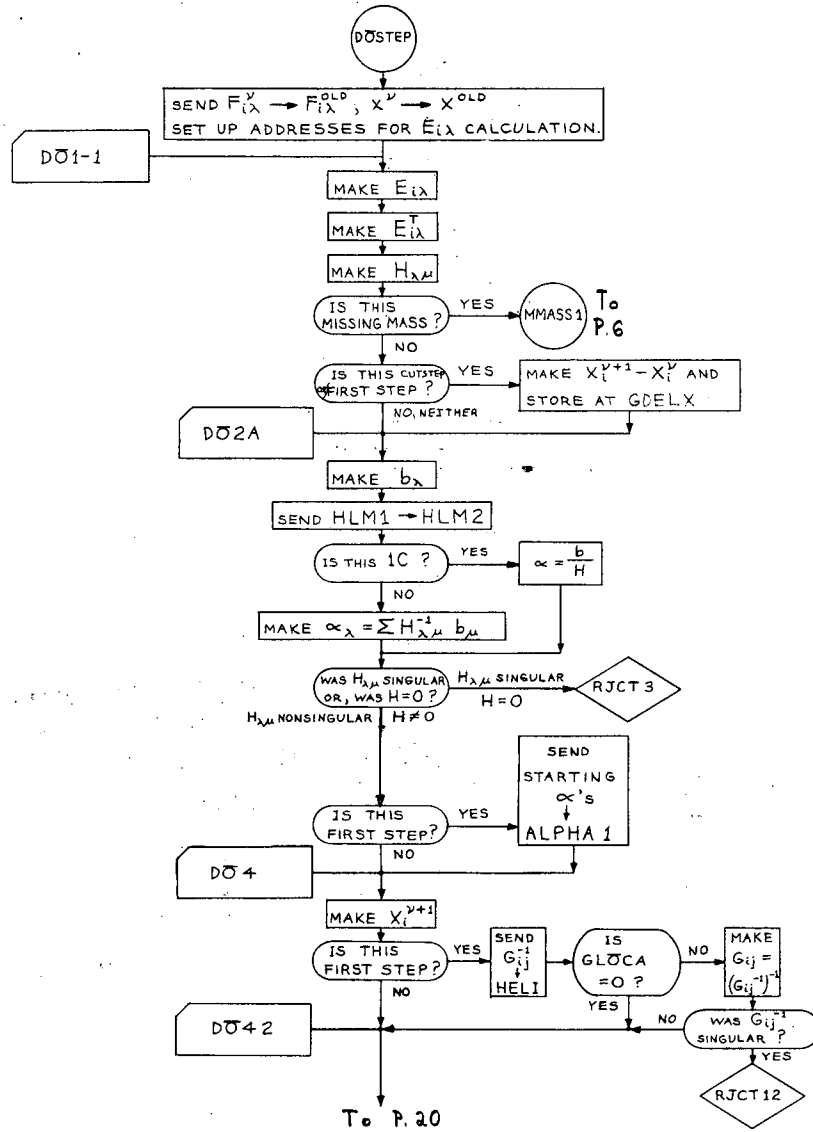


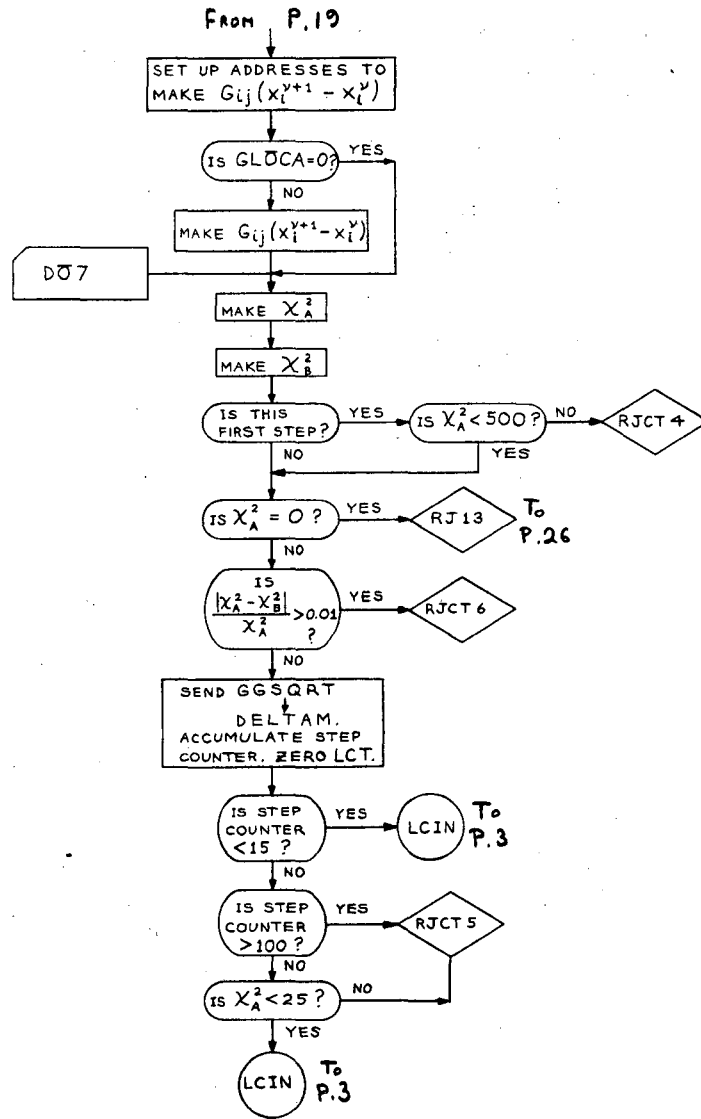
Note: It has been proved [see Alvarez Memo 180] that  $SM < \epsilon_3$  is not a desirable convergence criterion. Therefore in later versions of GUTS (cf. overall flow diagram), if  $\sqrt{(F^{nu+1})^2} < \epsilon_2$ , the second fit obtained is accepted. If  $\sqrt{(F^{nu+1})^2} > \epsilon_2$ ,  $F^{nu+1} = F^{nu} H(F^{nu})^T$  is computed. If  $F^{nu+1} < F^{nu}$ , another step is taken; otherwise the step is cut.

This replaces p.17 below the dashed line, and all of p.18 above the dotted line. To P.19

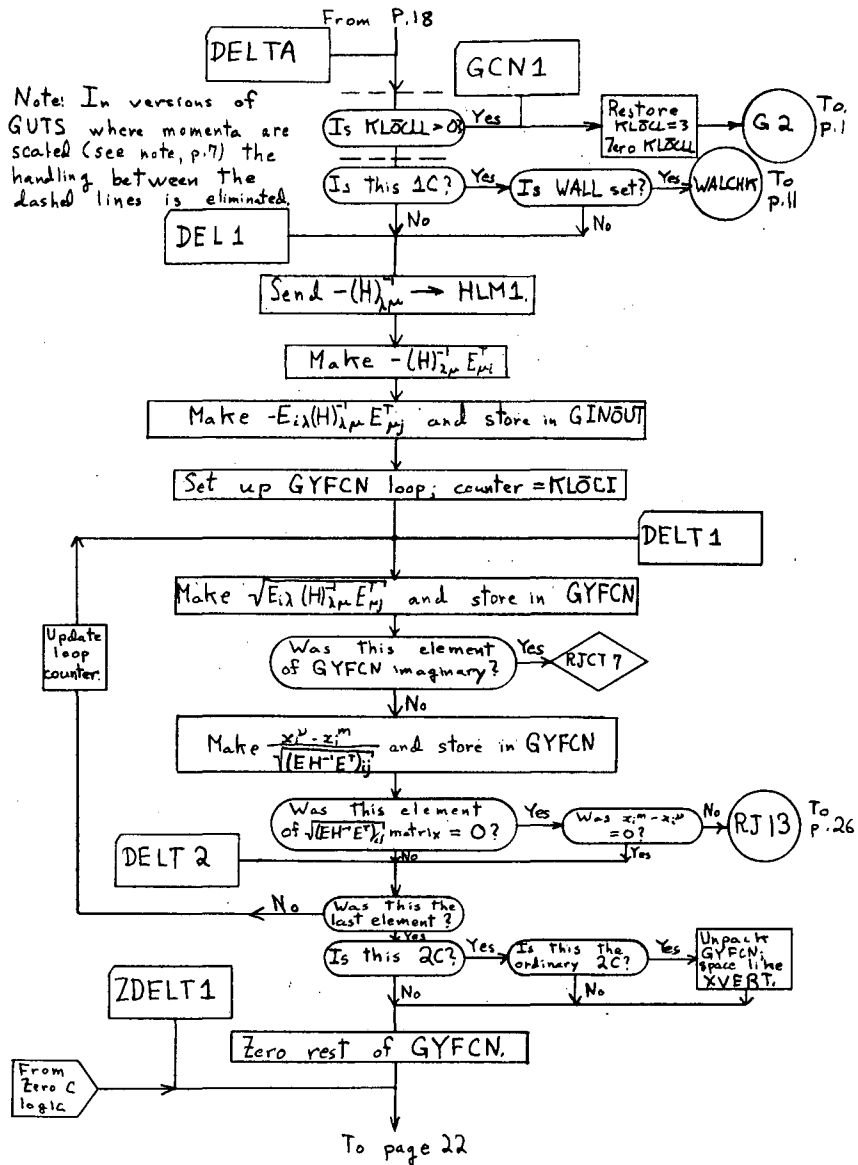


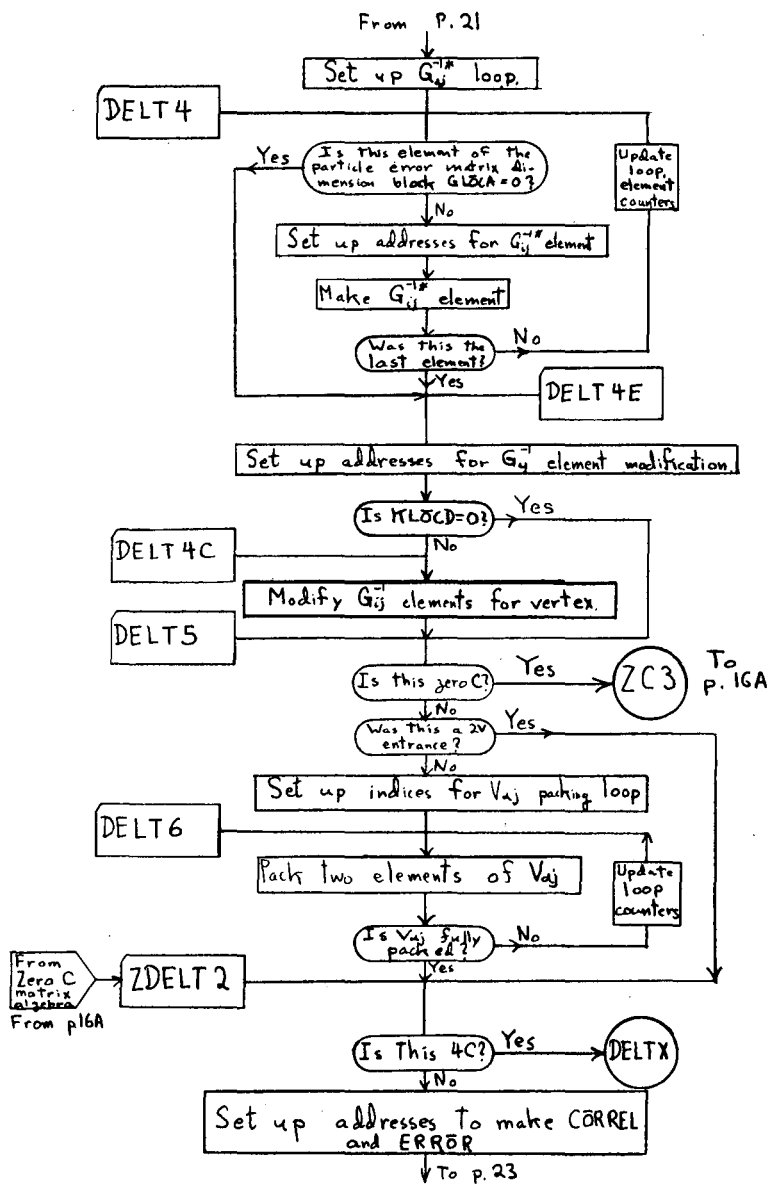




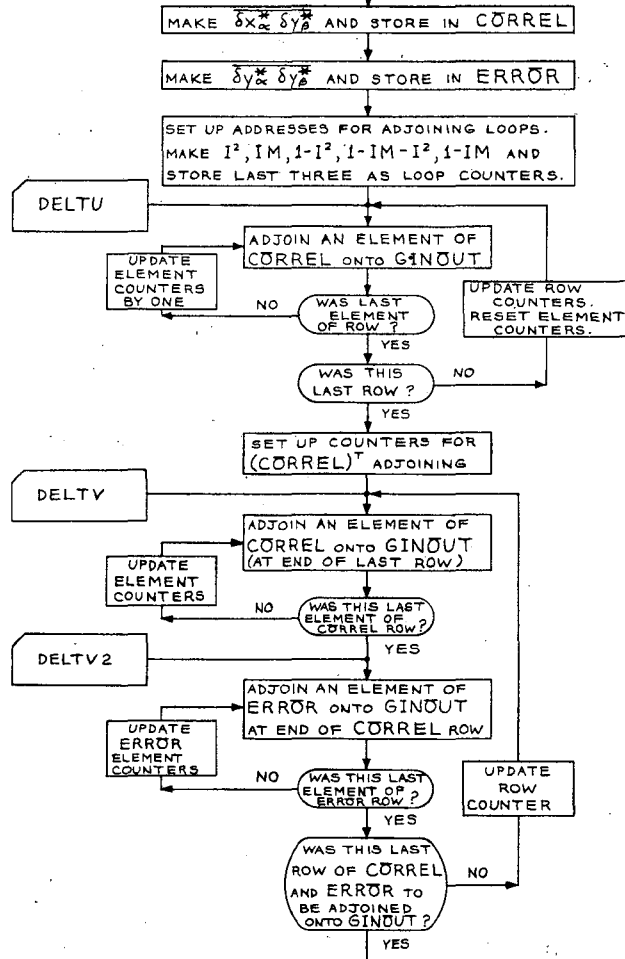


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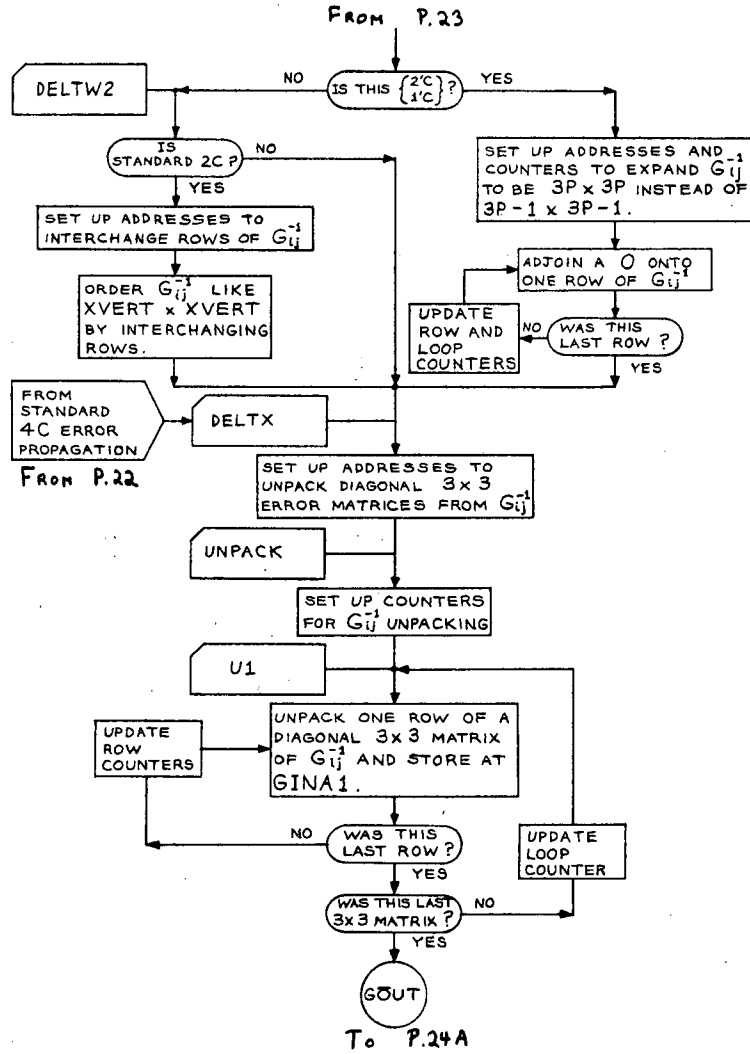


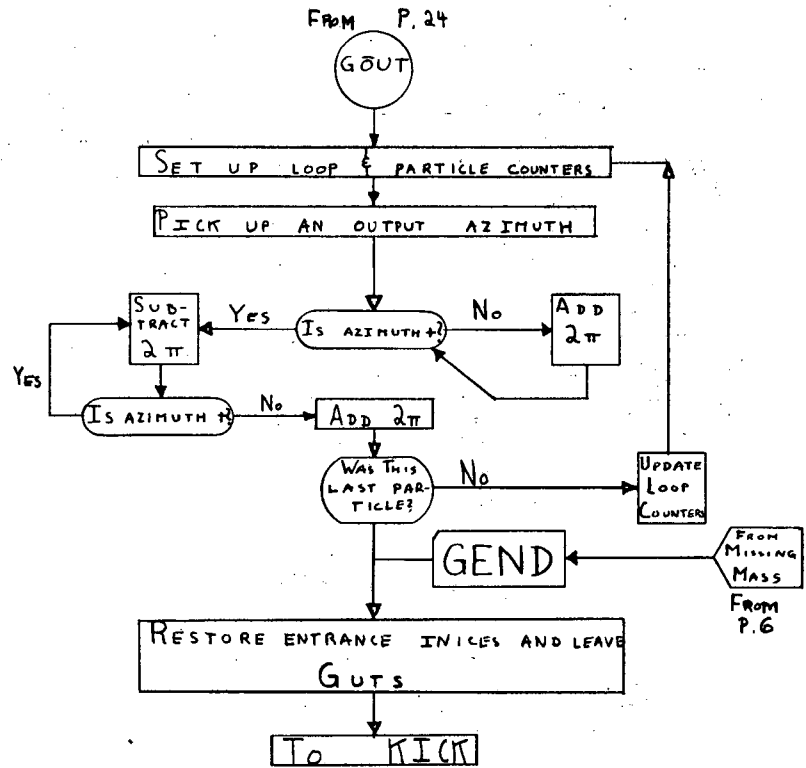


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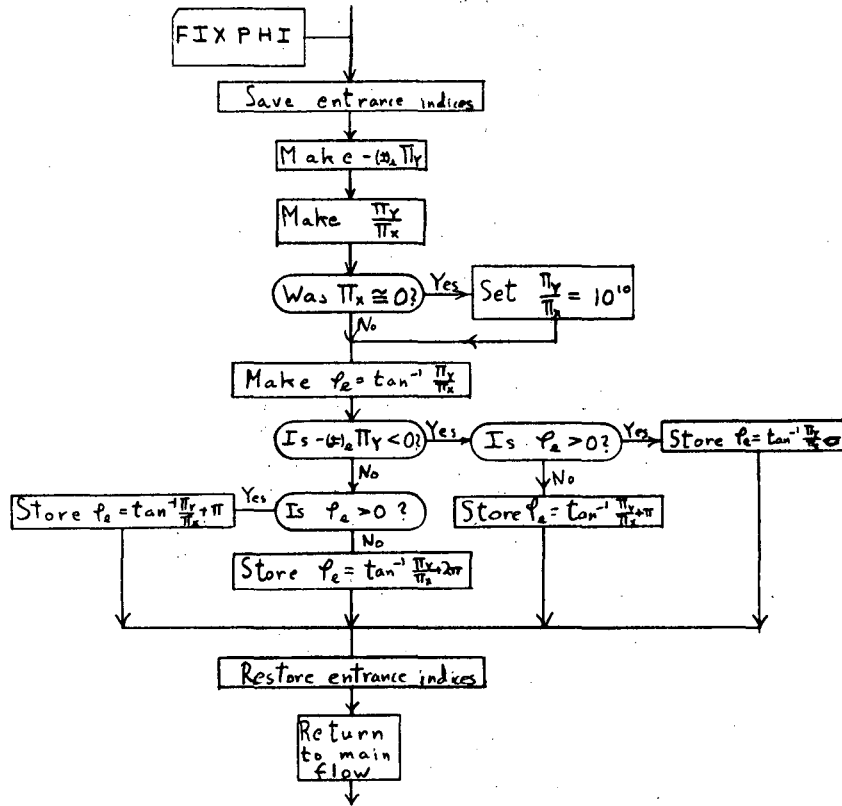


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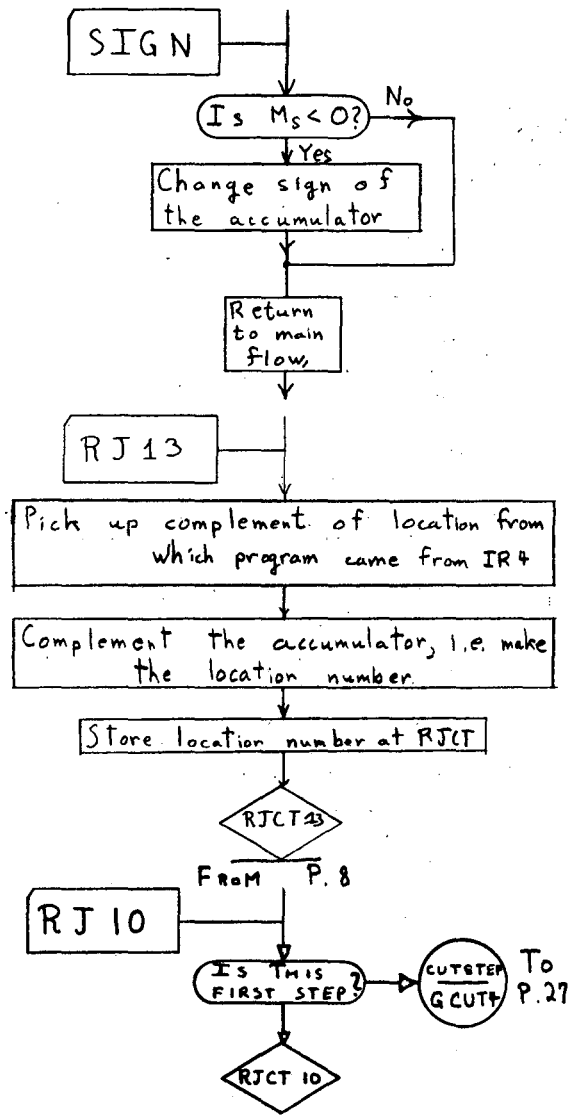


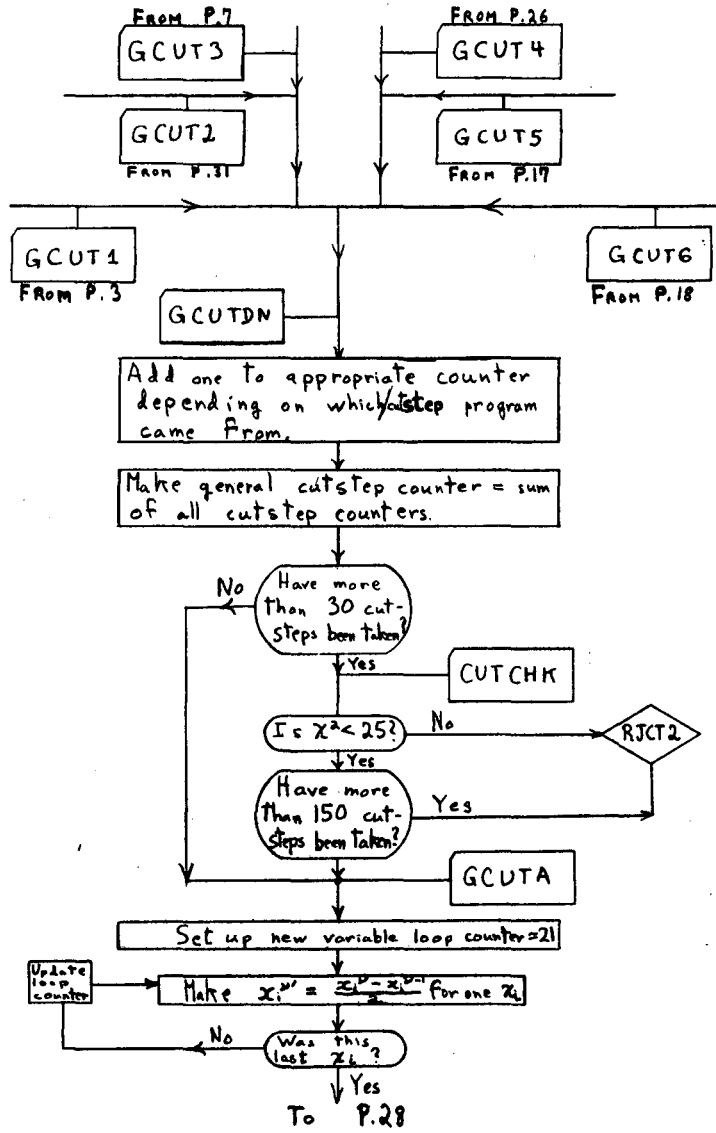
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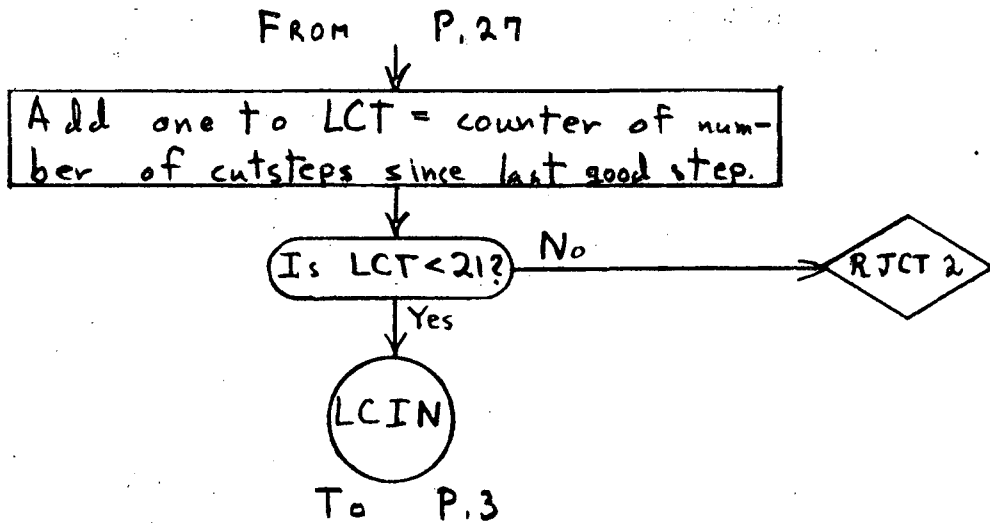
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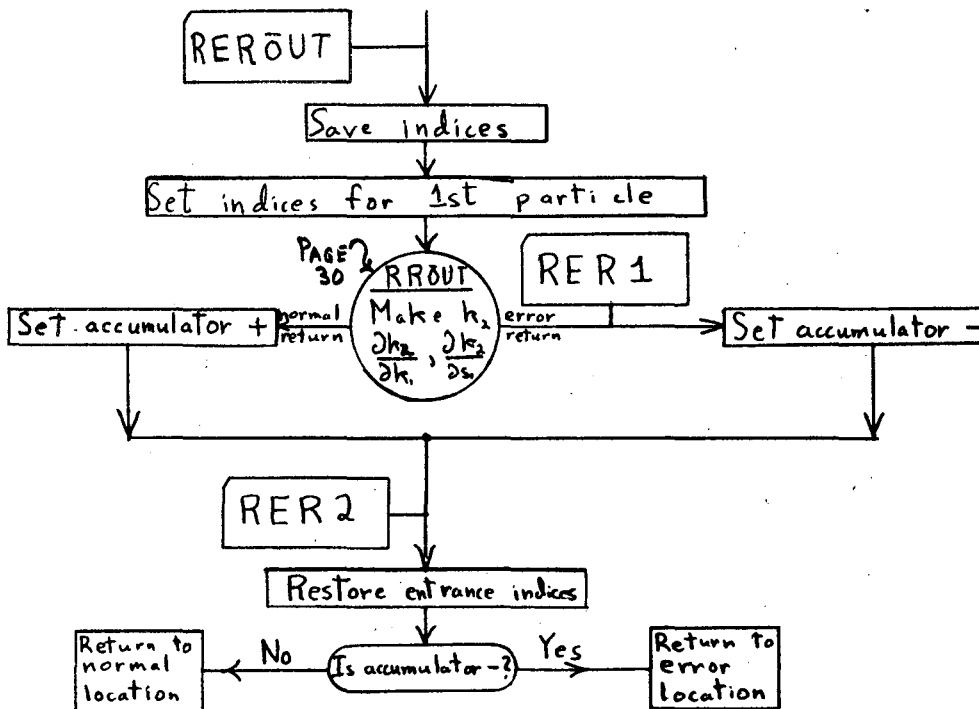




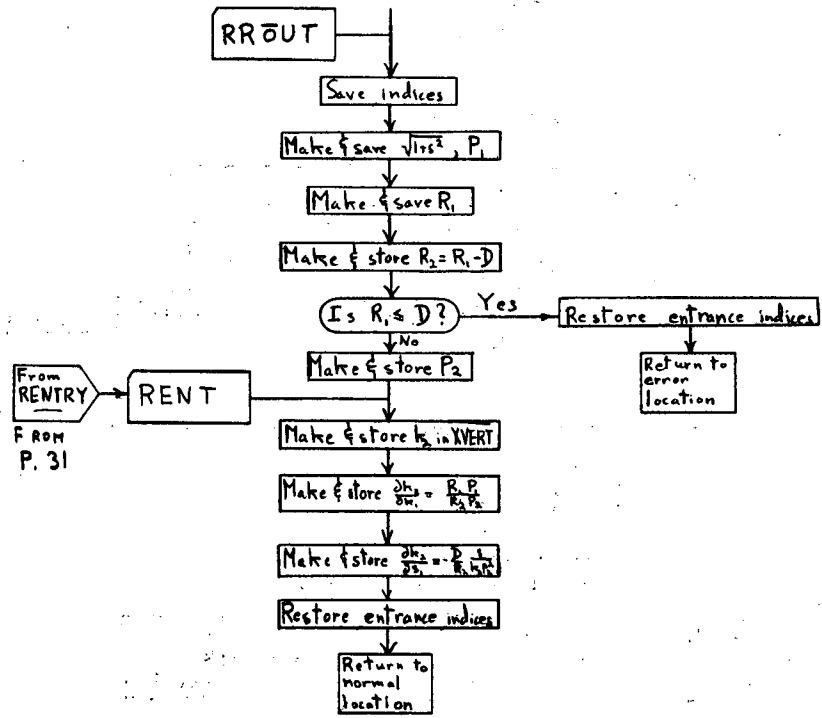
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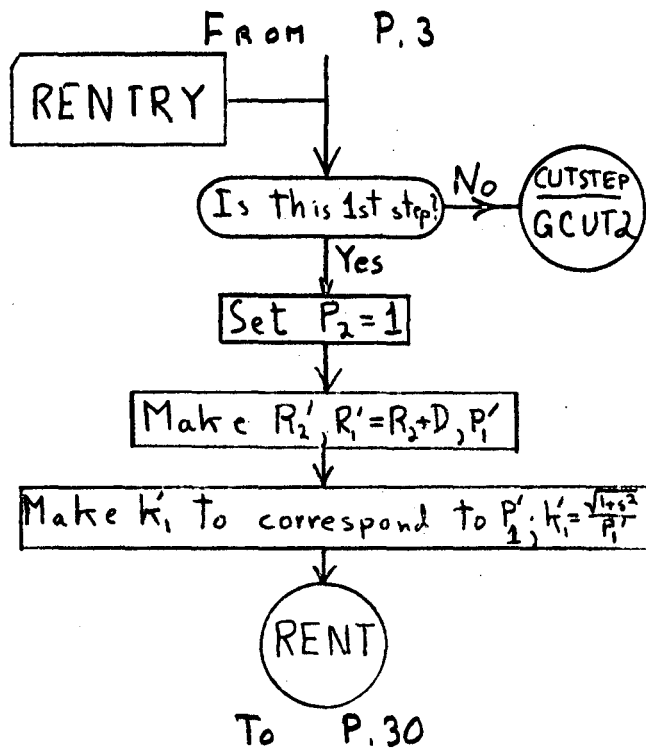
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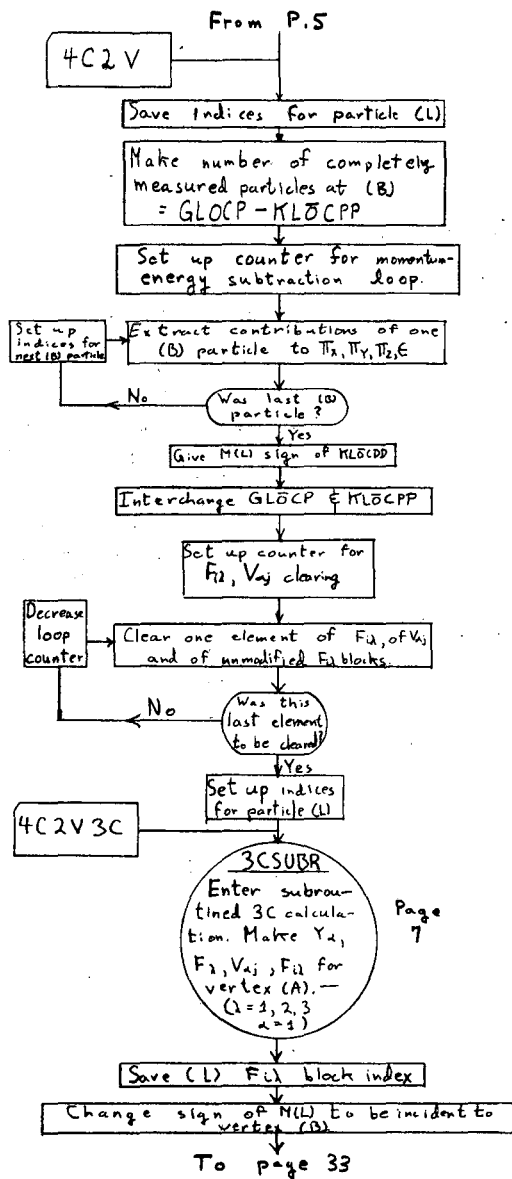
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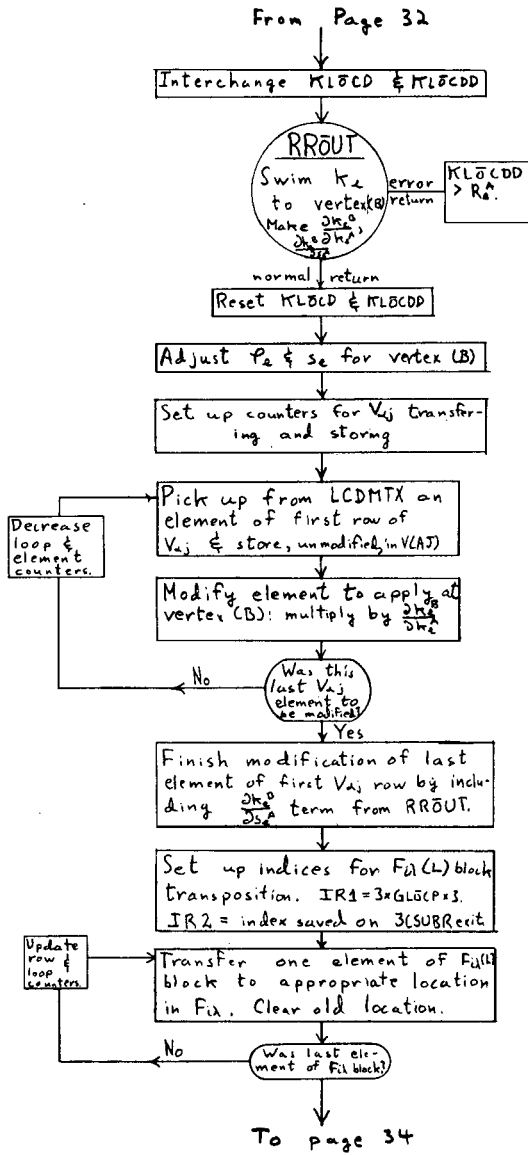


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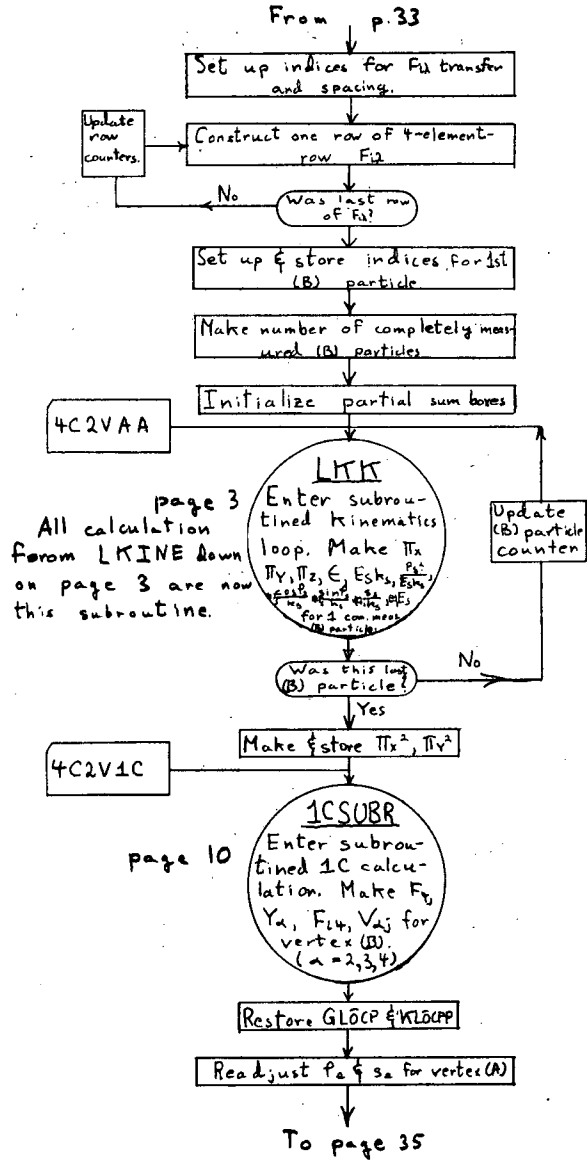
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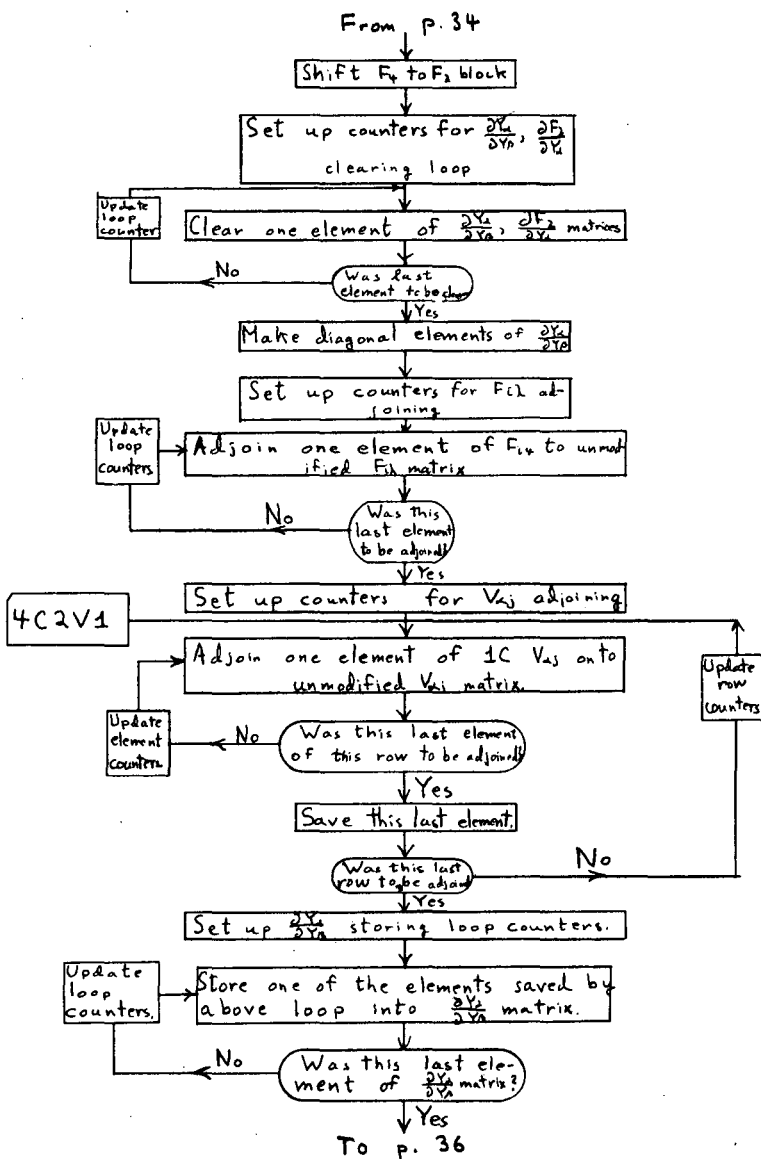


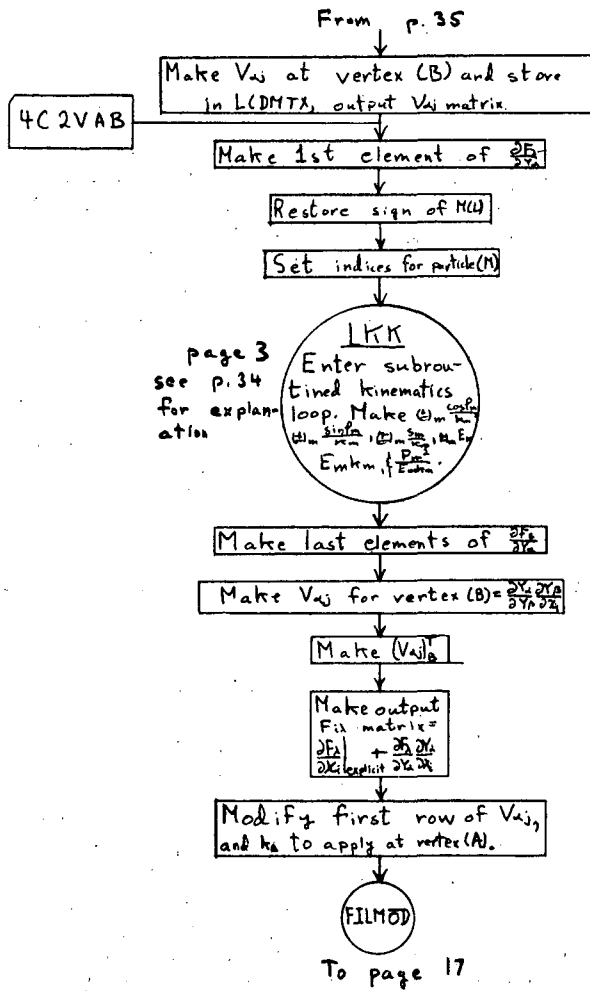


Note: In versions of GUTS which include 4C2V this is handled by scaling momenta by a factor of 1.05 This handling also replaces the 3C bypass handling GCNTR1 on page 7.









ACKNOWLEDGMENTS

We would like to thank Jon Peter Berge for his invaluable assistance, and we are indebted to Dr. Arthur H. Rosenfeld and Dr. Frank T. Solmitz for their helpful advice.

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APPENDIX I

List of rejects in present GUTS

- RJCT1: This is not used in the present version of GUTS.
- RJCT2: Too many cutsteps. If on some step after the first, one of five nonanalytic constraints is violated, that step is rejected and the size of the step that gave the violation is reduced by 1/2 for a new try. If a total of 30 cutsteps is taken, GUTS checks the size of  $\chi^2$ . For  $\chi^2 > 25.0$ , the event is rejected. For  $\chi^2 < 25.0$ , the fitting process is continued. If at any time there are more than 21 cutsteps between successful steps, the event is rejected. If more than 500 total cutsteps are taken, the event is rejected. Cutsteps come in five brands. These cutsteps are counted separately and occur in KICK OUTPUT.
  - GCUT1 Some k became  $< 0$ .
  - GCUT2 The incident track undershot KLOCD.
  - GCUT3 In 3C,  $P_1^2$  or  $E_1 < 0$ .
  - GCUT4 In 2C,  $k_1$  or  $k_m < 0$ .
  - GCUT5 The constraints have not yet been satisfied, and they failed to improve on the previous step.

GCUT is the sum of all these cutsteps.
- RJCT3:  $H_{\lambda\mu}^{\nu}$  was singular.
- RJCT4:  $\chi^2 > 500$  on the first step.
- RJCT5: Too many iterations. If GUTS takes 15 steps without obtaining a fit,  $\chi^2$  is checked. For  $\chi^2 > 25.0$ , the fit is rejected. For  $\chi^2 < 25.0$  up to 250 steps are allowed.
- RJCT6:  $\left| \frac{\chi_A^2 - \chi_B^2}{\chi_B^2} \right| > \text{CHECK}$ , CHECK is set at present to 0.01. The actual ratio is printed to KICK PRINT as DELTAM.
- RJCT7: Some GYFCN =  $\frac{\chi_i^{\nu} - \chi_i^m}{\{(E H^{-1} E^T)_{ij}\}^{1/2}}$
- RJCT8: FNORM was imaginary.
- RJCT9: Not in present GUTS (in earlier assemblies this means that DELM was imaginary.)

- RJCT10: In 2C on first step,  $k_l$  or  $k_m$  was  $< 0$ .
- RJCT11: This not used in present GUTS.
- RJCT12:  $G_{ij}^{-1}$  is singular.
- RJCT13: A divide check occurred, showing that some quantity computed by GUTS was zero. The 5-digit octal address of the command where the divide check occurred is found as RJCT in KICK OUTPUT.
- RJCT14: Zero C, ZCCTR1 = 0, the curvature as specified by DAMN became negative.
- RJCT15:  $P_\mu$  was imaginary in zero C.
- RJCT16: This is not used in the present GUTS.
- RJCT17: This is not used in the present GUTS.
- RJCT18: In the missing-mass calculation,  $\delta M^2 < 0$ . Here M has been found and put into MMASS.  $\sqrt{|\delta M^2|}$  has been put into DMMASS.
- RJCT19: This is not used in the present GUTS.
- RJCT20: The missing-mass calculation was entered with KLOCL  $\neq 4$ .
- RJCT21: Some input  $k_i = 0$  when it shouldn't be.
- RJCT25: ZCCTR1  $\neq 0$  and both signs of DAMN lead to  $k_u < 0$ .  
In zero C, for ZCCTR1 = 0, the discriminant is assigned the algebraic sign of DAMN. For ZCCTR1  $\neq 0$ , the sign of  $k_u$  is checked. For  $k_u < 0$ , the other sign of DAMN is tried. For both  $k_u < 0$  the event is rejected.
- RJCT27: Zero C, KLOCD  $\neq 0$ , incident particle undershot KLOCD.

There are really two kinds of reject. The first types can happen frequently.

These rejects are

Reject 2, 4, 5, 14, 15, 20, 25, 27.

The remaining rejects should happen rarely. These can happen only through rounding errors or misprogramming.\* They are

Reject 3, 6, 7, 8, (9), 10, 12, 13, 18, 21.

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\* If any examples of these rejects occur please notify Arthur Rosenfeld, Lawrence Radiation Laboratory, who will take appropriate action.

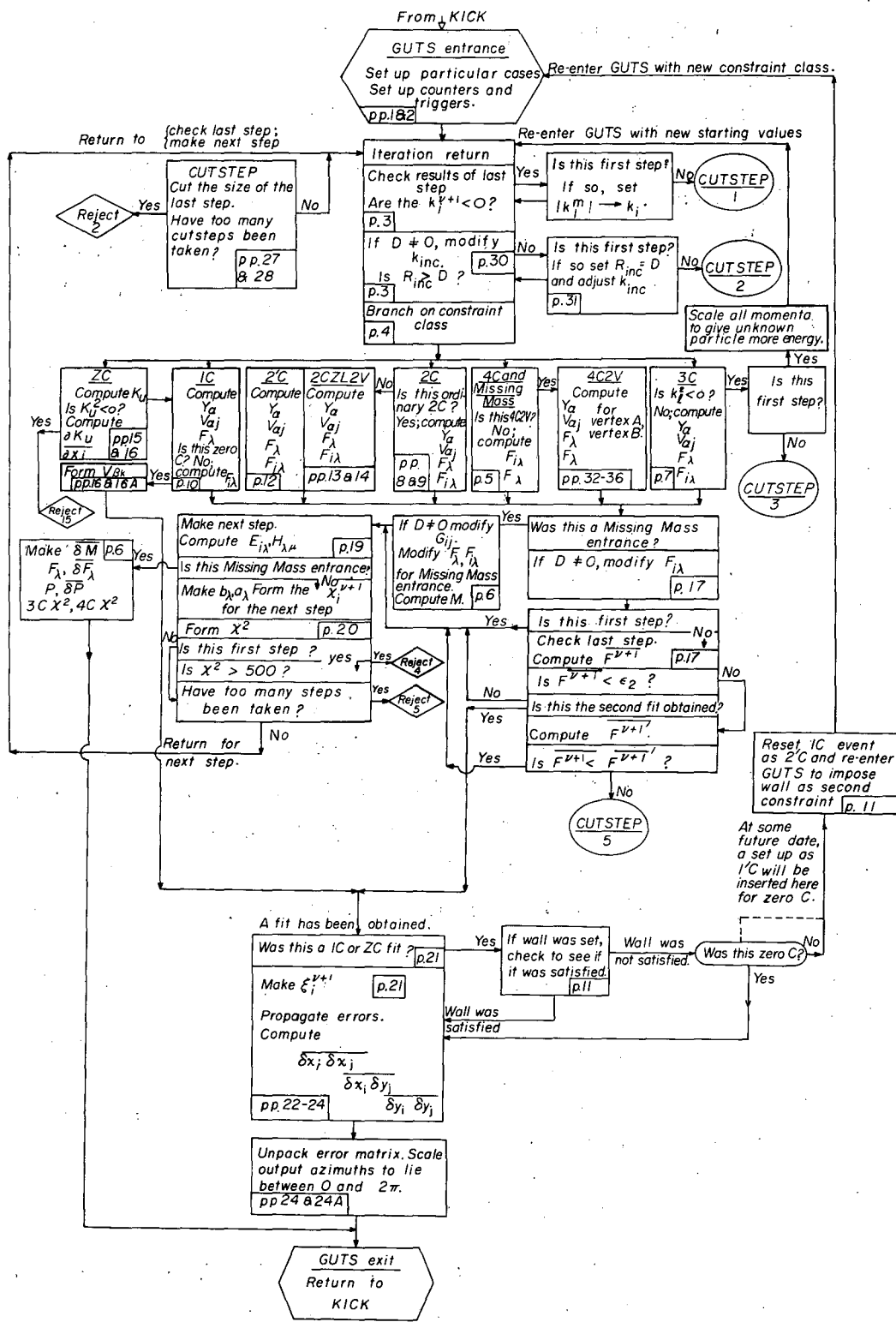


Fig. 1. Over-all flow diagram.

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